AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!

163fa21t1a – Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$e = 1.602 \times 10^{-19}$ C $\quad k = 8.99 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2} \quad c = 3.00 \times 10^{8}\ \frac{\text{m}}{\text{s}} \quad \varepsilon_0 = 8.85 \times 10^{-12}\ \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}$

$h = 6.626 \times 10^{-34}\ \text{J}\cdot\text{s} \quad hc \approx 1240\ \text{eV}\cdot\text{nm} \quad \mu_0 = 4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}} \quad 1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$

$m_p = 1.673 \times 10^{-27}$ kg $\quad m_e = 9.11 \times 10^{-31}$ kg

$\vec{F} = q\vec{E} \quad k = \frac{1}{4\pi\varepsilon_0} \quad \Delta x = v_{ix}t + \frac{1}{2}a_x t^2 \quad v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x$

$\vec{F}_{1on2} = \frac{kq_1q_2}{r_{12}^2}\hat{r}_{1to2} \quad \vec{E} = \frac{kq}{r^2}\hat{r} \quad V = \frac{kq}{r} \quad U_{12} = \frac{kq_1q_2}{r_{12}}$

$\oint \vec{E}\cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0} \quad q_{enc} = \int \rho dV \quad E_{\parallel\, plates} = \frac{|\Delta V|}{d} = \frac{\sigma}{\varepsilon_0} \quad E_{plate} = \frac{\sigma}{2\varepsilon_0}$

$E_{ring} = \frac{kQz}{(R^2+z^2)^{3/2}} \quad V_{ring} = \frac{kQ}{(R^2+z^2)^{1/2}} \quad E_x = -\frac{dV}{dx} \quad V_b - V_a = -\int_a^b \vec{E}\cdot d\vec{s}$

$\Delta U = q\Delta V \quad U_C = \frac{1}{2}Q_C\Delta V_C \quad Q_C = \Delta V_C C \quad I_C = -C\frac{dV_C}{dt}$

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots \quad C_{eq} = C_1 + C_2 + \cdots \quad C_{plates} = \frac{\varepsilon_0 A}{d} \quad C' = \kappa C$

$R_{eq} = R_1 + R_2 + \cdots \quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \quad R = \frac{\rho L}{A} \quad \rho = \rho_0(1 + \alpha\Delta T)$

$\Delta V_R = I_R R \quad \mathcal{P}_R = I_R\Delta V_R \quad X(t) = X_f + (X_i - X_f)e^{-t/\tau}$ where $\tau = RC$ or $\frac{L}{R}$

$\vec{F} = q\vec{v}\times\vec{B}_{ext} \quad \vec{F} = I\int d\vec{s}\times\vec{B}_{ext} \quad \vec{\tau} = \vec{\mu}\times\vec{B}_{ext} \quad \vec{\mu} = NI\vec{A}$

$U = -\vec{\mu}\cdot\vec{B}_{ext} \quad B_{sol} = \frac{\mu_0 NI}{L} \quad B_{circle} = \frac{\mu_0 I}{2a} \quad B_{straight} = \frac{\mu_0 I}{2\pi a}$

$\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{enc} \quad I_{enc} = \int \vec{J}\cdot d\vec{A} \quad \vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{s}\times\hat{r}}{r^2} \quad \Phi_B = \int \vec{B}\cdot d\vec{A}$

$EMF = -N\frac{d}{dt}\Phi_B \quad EMF = B_\perp Lv \quad L = \frac{\Phi_B}{I} \quad U_L = \frac{1}{2}LI^2$

$\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1} \quad \Delta V_L = -L\frac{dI_L}{dt} \quad Z = \sqrt{R^2 + (X_L - X_C)^2} \quad \tan\phi = \frac{X_L - X_C}{R}$

$X_L = \omega L \quad X_C = \frac{1}{\omega C} \quad V_{source} = V_0 \sin\omega t \quad i = i_{max}\sin(\omega t - \phi)$

$\Delta V_{Rmax} = i_{max}R \quad \Delta V_{Lmax} = i_{max}X_L \quad \Delta V_{Cmax} = i_{max}X_C \quad V_{source\ max} = i_{max}Z$

$\Delta V_{max} = \frac{\Delta V_{pk-pk}}{2} \quad \Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}} \quad \omega_0 = \frac{1}{\sqrt{LC}}$

$\mathcal{P}_{avg} = I_{rms}\Delta V_{rms}\cos\phi = I_{rms}^2 R$

$c = f\lambda \quad k = \frac{2\pi}{\lambda} \quad \omega = 2\pi f = \frac{2\pi}{\mathbb{T}}$

$\vec{S} = \frac{\vec{E}\times\vec{B}}{\mu_0} \quad I_{avg} = S_{avg} = \frac{E_{max}B_{max}}{2\mu_0} = \left(\frac{1}{c}\right)\frac{E_{max}^2}{2\mu_0} = c\frac{B_{max}^2}{2\mu_0}$

$\frac{E_{max}}{B_{max}} = c \quad E_\gamma = hf = \frac{hc}{\lambda}$

$Rad.Pressure = \frac{Force}{Area} = \frac{S_{avg}}{c} \quad Photon\ momentum = p_\gamma = \frac{E_\gamma}{c}$

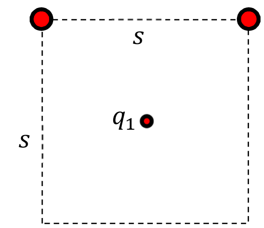
Material	**Resistivity** at 20° C (in SI units)	**Temp. Coefficient** (in SI units)
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Nichrome	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}

$\int \frac{x\,dx}{(x^2+a^2)^{3/2}} = \frac{-1}{\sqrt{x^2+a^2}}$	$\int \frac{dx}{\sqrt{x^2 \pm a^2}} = \ln\left\lvert x + \sqrt{x^2 \pm a^2}\right\rvert$
$\int \frac{dx}{(x^2+a^2)^{3/2}} = \frac{x}{a^2\sqrt{x^2+a^2}} = \frac{1}{a^2}\sin\theta$	$\int \frac{x\,dx}{\sqrt{x^2 \pm a^2}} = \sqrt{x^2 \pm a^2}$
$\int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\frac{x}{a}$	$\int \sqrt{x^2 \pm a^2}\,dx = \frac{1}{2}x\sqrt{x^2 \pm a^2} \pm \frac{a^2}{2}\ln\left\lvert x + \sqrt{x^2 \pm a^2}\right\rvert$
$\int \frac{x\,dx}{x^2+a^2} = \frac{1}{2}\ln\lvert x^2+a^2\rvert$	**Binomial expansion:** $(1 \pm \delta)^n \approx 1 \pm n\delta + \cdots$

WRITE YOUR NAME AT THE TOP OF THIS PAGE!!!!

A positive point charge with charge magnitude $q_1 = +e$ is released from rest at the center of a square of side s. A point charge is fixed in place at each of the top two corners of the square. Each of the top two charges has charge $+4e$. Assume the alignment of the charges is perfect. After q_1 travels very, very far from the fixed charges it moves with speed v. To be clear, assume gravitational forces are negligible for these point charges.

Notice the follow-up question at the bottom of the page!



****1a) Determine the mass of q_1.

1a	

1b) **What if?** Suppose the above experiment was repeated with equal charges but q_1 had twice the mass. How would the final speed of q_1 be affected (when it is far, far away from the fixed charges)? Circle the best answer.

Final speed doubled	Final speed quadrupled	Final speed increased by some other factor	Final speed unchanged
Final speed halved	Final speed divided by 4	Final speed decreased by some other factor	Impossible to determine without more info

A two-charge code fragment is shown at right. Assume all forces other than the Coulomb force are negligible.

***2) Write out code which would compute and output the *acceleration vector* of charge `c1` caused by the Coulomb force exerted by charge `c2`.

You are expected to use about 3-7 lines of code to complete this task.

```
1  GlowScript 3.1 VPython
2  #assume SI units (kg, m, C) on all numbers
3
4  c1 = sphere( color=vec(1, 1, 0), radius=0.5 )
5  c1.pos = vec(3.2415,-1.254,9.743015)
6  c1.q = 2.5749186543245e-6        #charge 1
7  c1.m = 1e-7                      #mass 1
8
9  c2 = sphere( color=vec(0, 1, 1), radius=0.5 )
10 c2.pos = vec(-2.45678,1.23456,9.87654)
11 c2.q = -1.35765987456e-6         #charge 2
12 c2.m = 1e-2                      #mass 2
```

Write the lines of code in the boxes included below.
It is ok to leave some lines blank!!!

Do not worry about sig figs, units, text in the code output, or code comments for this problem.

Note: you will get zero points for computing the answer with paper & pencil…please don't waste time on that.
I want code that computes the answer…not the answer.

Line 13	
Line 14	
Line 15	
Line 16	
Line 17	
Line 18	
Line 19	

An insulating spherical shell has inner radius R and outer radius $3R$. The shell carries non-uniform charge distribution given by $\rho = \frac{\alpha}{r}$ where α is an *unknown* positive constant. The electric field magnitude at the surface of the shell is E.

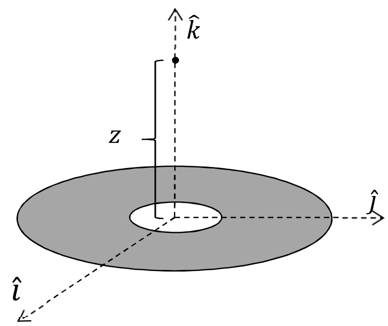
3a) What units are assumed for the constant α?

****3b) Determine an expression for the electric field valid for all radii inside the shell in terms of $r, R, \alpha, \& \, \epsilon_0$. To be clear, I am ok with the unknown parameter α being used in your final result.

3c) Determine α in terms of only known quantities.

3a	
3b	
3c	

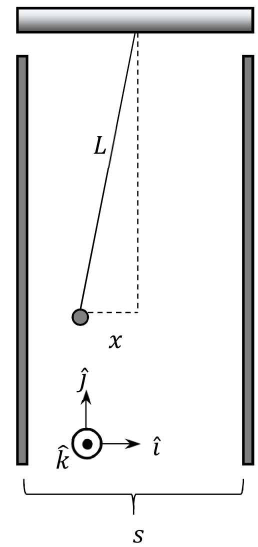
A thin washer has inner radius R_1 and outer radius R_2. The washer is centered at the origin and lies in the xy-plane as shown in the figure (not to scale). The washer carries total charge Q distributed uniformly. A point of interest is located distance z above the origin. Note: you may assume z is always a positive quantity.



*****4) Determine the electric *field* distance z (on-axis) above the center of the washer. I'm expecting the answer may not simplify down that well, thus the long answer box. The answer must be written in terms of the parameters given.

4	

A ball of mass m and charge q is suspended from the ceiling using an ideal string (massless, inextensible) of length L. The ball hangs midway between two conducting plates of extremely large size which each lie parallel to the yz-plane (see figure, not to scale). The plates are separated by distance s. A potential difference is applied across the plates. When the ball reaches equilibrium it is located distance x from the midline between the plates (see figure). For this problem, gravitational forces are NOT negligible. The ball is far from the fringing fields at the top and bottom ends of the plates. The angle from the vertical is small enough for the small angle approximation to apply ($\sin\theta \approx \tan\theta$). Note: the ball never touches the plates.



5a) Which plate is at lower potential? Circle the best answer.

Left Plate	Right Plate	Plates at Equal Potential	Impossible to determine without more info

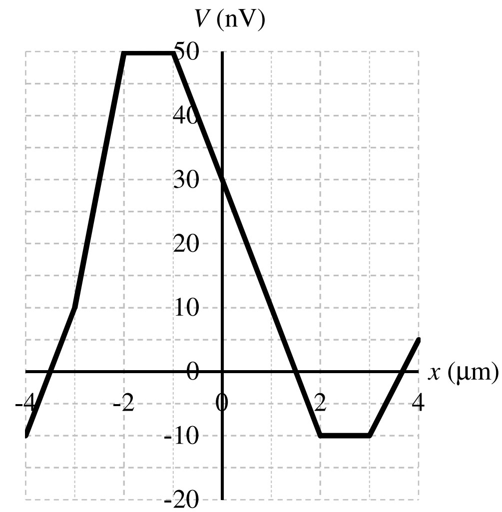
****5b) Determine the magnitude of the potential difference.

5a	

5c) Suppose the string was slightly longer while q, s, m & the unknown potential difference remained the same. How, if at all, would the parameter x differ compared to the initial scenario? Circle the best answer.

x increases	x decreases	x unchanged	Impossible to determine without more info

A plot of potential versus position is shown for an electron constrained to 1D motion. The electron is located at $x = 1.00\ \mu\text{m}$. You may assume a standard coordinate system here ($\hat{\imath} = to\ the\ right, \hat{\jmath} = upwards$).



****6a) Determine the force *magnitude* on the electron.
Answer using scientific notation.

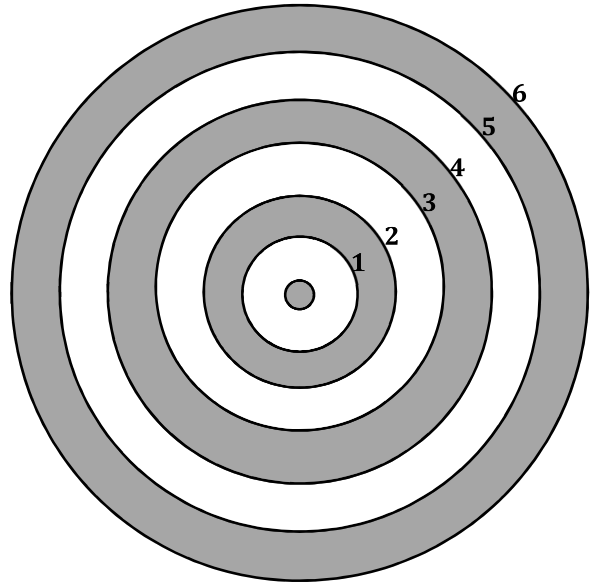
6a	

6b) Which of the following best describes the *direction* is the force on the electron? Circle the best answer.

<table>
<tr><td>Upwards</td><td>To the right</td><td>Upwards &
to the right</td><td>Upwards &
to the left</td><td rowspan="2">Impossible to determine without more info</td></tr>
<tr><td>Downwards</td><td>To the left</td><td>Downwards &
to the right</td><td>Downwards &
to the left</td></tr>
</table>

6c) If released from rest, at what horizontal position would the electron reverse direction? Note: if the electron would travel past $x = \pm 4.00\ \mu\text{m}$, please answer "electron does not reverse direction".

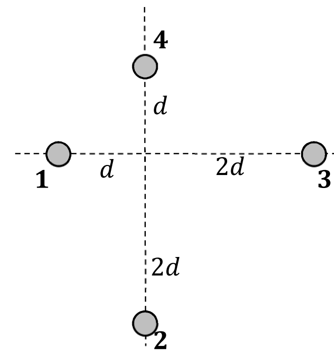
A set of spherical shells concentrically surround a point charge with charge Q. Each shell is a conductor and each shell also carries charge Q. The radii of the shells are indicated with numbers as shown in the figure. For example, the outmost radius would be called R_6. Assume all radii are known.



7a) Determine the surface charge density at radius R_5.
7b) Determine an equation for the electric field magnitude for points between radii R_4 & R_5.

7a	
7b	

Four point charges are arranged as shown in the figure and labeled with numbers. The distance from the origin to each charge is indicated in the figure as either d or $2d$. Charges are:



- $q_1 = -e$
- $q_2 = +2e$
- $q_3 = -3e$
- $q_4 = +e$

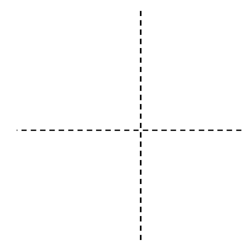
8a) Which best describes the electric *potential* at the origin?

Positive	Negative	Zero	Impossible to determine without more info

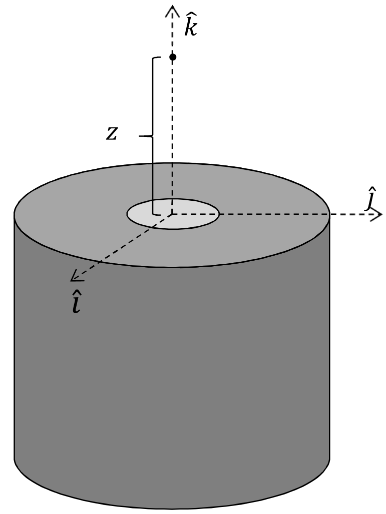
8b) Which best describes the *direction* of the electric *field* at the origin?

<table>
<tr><td>Upwards</td><td>To the right</td><td>Upwards & to the right</td><td>Upwards & to the left</td><td rowspan="2">Zero field at the origin</td><td rowspan="2">Impossible to determine without more info</td></tr>
<tr><td>Downwards</td><td>To the left</td><td>Downwards & to the right</td><td>Downwards & to the left</td></tr>
</table>

****8c) Determine the electric field direction.
Express your answer as a numerical value of an angle from the positive x-axis.
Include a sketch showing the angle in the answer box to add clarity to your answer.

8c	

Extra credit is often time consuming and worth very few points. You are almost always better off focusing on regular credit. I suggest you only attempt the extra credit after you have checked your work for all other parts. Scores over 100% are not possible.



***__Extra credit:__ Determine the electric field distance z above the axis of a thick-walled cylindrical pipe. Assume total charge Q is uniformly distributed. The height of the pipe is L. Inner & outer radii of the pipe are R_1 & R_2 respectively.

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